Space Biology Virtual Workshop
January 20–21, 2021
Program and Abstracts

Times listed are U.S. Central Standard Time (GMT -6)

Wednesday, January 20, 2021	
9:00 a.m.–12:10 p.m. CST	LSSW Space Biology: Plenary Talks
12:30–3:10 p.m. CST	LSSW Space Biology: Abstract Talks Day 1
Thursday, January 21, 2021	
9:00–11:45 a.m. CST	LSSW Space Biology: Abstract Talks Day 2
11:55 a.m.—4:30 p.m. CST	LSSW Space Biology: Break Out Sessions Day 2
5-minute pre-recorded presentations	LSSW Space Biology: Posters

Wednesday, January 20, 2021
LSSW SPACE BIOLOGY: PLENARY TALKS
Chairs: Kevin Sato, Sharmila Bhattacharya

9:00 a.m. Craig Kundrot *
Introduction and Welcome
9:10 a.m. Kevin Sato *
Agenda, Goals, and Expectations for LSSW
9:20 a.m. Sharmila Bhattacharya *
Space Biology Research Beyond LEO
9:40 a.m. Steven Platts *
Human Lunar Science Research
10:00 a.m. Lisa Pratt, Planetary Protection Officer, NASA Headquarters
Planetary Protection Research
10:20 a.m. BREAK
10:30 a.m. Lindsay Hays, Program Scientist, NASA Astrobiology Program
Astrobiology
10:50 a.m. Julie Robinson *
Overview of HEO Lunar Science Utilization and Capabilities
11:10 a.m. Debra Needham, Program Scientist, NASA Exploration, NASA Exploration Science Strategy and Integration Office
CLPS Lander Utilization
11:30 a.m. Noah Petro. Lab Chief – Planetary Geology, Geophysics, and Geochemistry Laboratory, NASA Goddard Space Flight Center *
Artemis III SDT Report
11:50 a.m. Harlan Spence *
Lunar Surface Environment
12:10 p.m. BREAK

Wednesday, January 20, 2021
LSSW SPACE BIOLOGY: ABSTRACT TALKS DAY 1
Chairs: Kevin Sato and Sharmila Bhattacharya
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12:30 p.m. Kiss J. Z. * McKay C. P. Bowman R. N.
The Effects of Lunar Gravity on Plant Growth and Development **[#2003] Plant and Plant Enabling Technology**
Numerous studies on plant growth and development have been performed in the microgravity environment since the beginning of human spaceflight. In contrast, there are very little data to show how plants will grow in the partial gravity and high radiation environment on the surface of the Moon or Mars. How biology responds to partial gravity remains relatively unexplored. Only recently have studies with small centrifuges on the ISS begun investigations at partial gravity to test the response of plants at partial gravity. We performed experiments on the ISS on the interaction between gravitropism (directed growth in response to gravity) and phototropism (directed growth in response to light) using the model plant Arabidopsis thaliana in microgravity and reduced/partial gravity. These experiments utilized the European Modular Cultivation System (EMCS) which has onboard centrifuges allowing for gravitational accelerations ranging from microgravity to partial gravity to a 1g control.In contrast to our results at 1g, we observed a robust positive phototropic curvature in response to unidirectional red illumination in stems and roots of plants that developed in microgravity. In time course studies, stems of seedlings showed a positive phototropic curvature relative to red light in µg and 0.1g conditions, and the mean curvature was not significantly different between these treatments. In contrast, the response at 0.3g was not significantly different from the response of the control (1g). This range of reduced gravity (relative to the Earth) is in the approximate range of gravity levels on the Moon (0.17g) and Mars (0.38g). If we extrapolate the results of gravity effects on phototropism to other aspects of plant biology, it is possible that plants that will be grown in greenhouses in the reduced gravities on Mars may have many mechanisms of plant physiology similar to the 1g level that is Earth nominal. However, plants may behave differently on the Moon given our results and the lower gravitational acceleration on that planet. The prediction from these results is that lunar gravity may pose issues for plant growth while Martian gravity may be adequate. Thus, our spaceflight results on the ISS have profound implications for human exploration plans and for the use of a Moon Base as a stepping stone to Mars. In addition, our goal is to verify our ISS partial g results on a proposed lunar lander experiment.

12:40 p.m. Monje O. * Nugent M. Tucker R. Romeyn M. Fritsche R.
Lunar Lettuce — Food for Lunar Crewed Missions **[#2005] Plant and Plant Enabling Technology**
We propose to demonstrate leafy crop production system for an entire crop life cycle on the Moon under the combined effects of deep space ionizing radiation and partial gravity with minimal crew time and no sample return.The originally submitted abstract was peer reviewed and is available at: https://www.hou.usra.edu/meetings/lunarsurface2020/pdf/5064.pdf

12:50 p.m. Clark P. E. * Gilroy S. Elliott J. Voecks G. Coleman M. et al.
LARGE: Lunar Amended Regolith Gardening Experiment **[#2009] Plant and Plant Enabling Technology**
We are developing a first-of-its-kind demonstration to confirm that lunar regolith has the potential to be developed into a medium for the growth of food resources for astronauts. We test the hypothesis that lunar regolith will release sufficient quantities of mineral nutrients to support plant growth by monitoring the process of germination and growth of seeds under Earth atmosphere (STP) in sampled lunar regolith on the lunar surface, after adding water and varying amounts of inorganic supplements of defined composition. LARGE would monitor plant growth (via fast germinating radish seeds) and relate its rate to the aspiration of reactants within the regolith and atmosphere and assess the effects of added supplements. Water amount and placement, seed preparation and placement, illumination, radiation, temperature, and pressure will be controlled, with varying proportions of supplements added in up to 12 chambers. In each chamber, atmospheric CO_2, T, P, and humidity; soil oxygen, pH, and selected cation abundance will be monitored. Time lapse visual images will be used to determine germination time and plant growth. Soil type will be determined with pre-sampling micro Vis/NIR spectrometer. The instrument consists of an enclosure attached below a landing deck. In the enclosure, where STP (one Earth atmosphere) conditions are maintained with an air tank, is a rotating cylindrical carousel containing twelve plant growth cells. Cells are designed to determine bioavailability of minerals in fully wetted lunar regolith with varying proportions of basic nutrients virtually

unknown in lunar regolith, such as nitrogen. Cells have an upper portion, where sensors, seeds, the water and nutrient sources are maintained, and lower portion, which acts as a sampler. A linear actuator assembly drives samplers based on successful Apollo drive tube regolith collectors, one at a time, into the lunar regolith. The sample is then rotated into position for sealing the bottom of the lower portion and sealing the bottom to the top portion. Water deployer (syringe) and sensors with seeds attached in the top portion are driven into the sample and sealed. Cells are pressurized, nutrient-containing water added, the water dissolving the seed coatings, and monitoring begins. This work was performed in part at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA. Pre-decisional information for planning and discussion purposes only.

1:00 p.m. Schultz E. R. *

Multigenerational Phenomics of Cowpea (Vigna unguiculata) in Lunar Environment for Dietary Supplementation in Future Colonization **[#2022] Plant and Plant Enabling Technology**

The challenge of renewable protein sources is important for establishing extraterrestrial colonies. Cowpea has a protein-rich nutritional profile, tolerates suboptimal environments, and cycles in as little as 60 days in the right environmental conditions. This proposal seeks to explore the effects of the lunar growth environment on cowpea across generations in a plant-focused and cross-disciplinary study. This investigation has three aims: to characterize the growth and development of cowpea grown in lunar greenhouse or controlled environment (CE) conditions, to evaluate the yield and nutritional profile from spaceflight-grown cowpea across two or more generations, and to evaluate compost from crop growth as lunar regolith supplement to improve quality.The plants used in this study can contribute greatly to the overall knowledge of physiological responses of plants to growth in an extraterrestrial environment. Corteva Agriscience has extensive molecular biology capabilities with which to study plant responses, such as transcriptomic, proteomic, and metabolomic laboratories, as well as management of CE. These capabilities can help identify key cellular and molecular systems for adaptation to lunar environments. Pairing molecular data with morphometric and yield data would provide a more complete picture of lunar agriculture. Simple automated imaging systems (RGB) would provide valuable physical and IR data to supplement yield data, with opportunity for advanced multi- or hyperspectral imaging systems.These three aims can be accomplished using minimal crew time. Dormant seeds would be launched and broken through hydration at planting, once lunar CE has been established. Morphometric data collection will begin through time-lapse imaging upon planting. Crew time would be required for sampling (in the form of leaf tissue for -omics) approximately 40 days after initial hydration. Samples would be fixed in RNAlater and stored at -80°C until return. Crew time would again be required approximately 90 days after hydration for harvest, at which point leaf samples would be collected. Remaining plant matter will be used for a substrate study by homogenizing plant material with lunar regolith. A subset of seeds from each generation will be stored in a breathable container for 12-15 days for dry-down, at which point they will be planted for the next generation study in the experimental lunar substrate.

1:10 p.m. Quincy, UB-I NASA C. D. Link, SURA B. M. * Levine, UB-A NASA H. G.

Understanding the Impact of the Deep Space and Lunar Environment on Crop Production and the Associated Microbiome **[#2023] Plant and Plant Enabling Technology**

Introduction: As Artemis advances to the Moon, women and men will be facing unique hazards. A critical risk to long duration space missions, and surface operations is ensuring that there will be sufficient nutritious food available to sustain a crew. High energy radiation damages DNA and may ultimately reduce an organisms' ability to survive or reproduce. Critical aspects relate to long term genetic stability in organisms. How long can seeds be stored? Is the damage cumulative from generation to generation? If so how many generations can you replant before suffering a crippling loss in nutrition or yield? Will foods rich in antioxidants help mitigate crew radiation exposure? Near Term: The first experiments will explore radiation damage by carrying spores (bacteria, yeast, fern), pollen or seeds to the vicinity of the moon and back with no handling or intervention. Fully sequencing progeny from returned organisms along with dosimetry from the vehicle will provide information on the rate of genome damage. These experiments weigh a few grams, require no power and no more volume than an envelope. Experiments with fully automated hardware will enable microbe and cell studies as well as tissue chip and organ on a chip experiments that are valuable for understanding both plant and animal responses to the lunar surface or orbital environments. The value of the science will be greatly increased by sample (but not hardware) return and are appropriate for CLPS or HLS landers.With minimal crew time (1–5 min every other day) microgreens could be grown in the HLS habitable volume using low mass systems being developed at Kennedy Space Center (KSC) demonstrating production of nutrient rich foods on

the surface of the moon. The value of the science would be greatly increased providing information on food safety, DNA damage, and activated gene networks by returning samples in a fixation device like the KSC Fixation Tube (KFT).Conclusions: Priorities on the earliest missions will be low mass and power use, minimal crew time requirements, high levels of automation, and disposability (low return mass). Understanding how biology is impacted by Lunar gravity, magnetic fields, radiation and closed ecosystems is critical to human survival and meeting NASA's deep space goals. Artemis will allow us to begin to address these essential elements enabling NASA's long term exploration mission in an environment that is not easily simulated on Earth.

1:20 p.m. Dixit A. R. * Khodadad C. K. Spern C. J.
Physcomitrella Patens, a Model System to Understand Deep Space and Lunar Surface Radiation Risks **[#2040] Plant and Plant Enabling Technology**
Rationale: Galactic cosmic radiation (GCR) induces various types of DNA damage. Among the types of damage, double-strand breaks (DSBs) are difficult to repair accurately and has the most serious biological consequences. Physcomitrella patens (moss) is unique among plants in its resistance to ionizing radiation, due to its high homologous recombination (HR) mediated DSBs repair activity. P. patens has been suggested to possess unique mechanisms such as increased activity of RAD51-1 recombinase and the ATR kinase that executes a cell-cycle checkpoint to inhibit induction and provide resistance to high numbers of DSBs. Method: In the proposed experiment, we will deploy a fully automated growth system with P. patens colonies pre-grown on a solid growth medium, either on a crewed or a cargo mission to the Moon with minimal to no intervention by the crew. Once on the surface and exposed to the lunar environment, we will collect growth, development, environmental, and dosimetry data to understand the plant's responses. Once returned back to Earth, knowledge gained from studying and analyzing these samples will advance the science of how and why P. patens is radiation tolerant and what it can tell us about survivability of plants used for food production on the lunar surface. Justification: The lunar surface is the most appropriate environment to test Physcomitrella's radiation resistance as reproducing the GCR spectra on Earth is nearly impossible. In addition, the daily GCR dose equivalent on the surface of the Moon is around a factor of 2.6 higher than the dose inside the ISS. Therefore, science advanced from this study will help us develop strategies to inch towards the goal of self-sustainability in terms of growing food for the explorations beyond planet Earth.

1:30 p.m. Larkin E. M. * Correll M. J.
The Impact of Lunar Radiation and Gravity on Plant Growth and Rhizobiome Communities **[#2047] Plant and Plant Enabling Technology**
The near-constant light provided near Shackleton crater on the Moon provides an ideal location for Lunar agriculture research. While many of the Lunar environmental constraints can be approximated with Earth-based analogs, the reduced gravity and elevated radiation experienced on the moon cannot be accurately simulated. ISS research has demonstrated that biological processes are affected by altered gravity via direct (e.g., gravitropism) and indirect (e.g., fluid-dynamics) mechanisms. Radiation has long been known to interfere with biological processes. The reduced gravity of the Lunar surface can be simulated with a clinostat, however, these are impractical for the growth of space-agriculture relevant plants, such as lettuce. A frontier of agricultural research is uncovering the dynamics of plant-microbe relationships and leveraging these insights for more productive and stable agriculture systems. ISS experiments are slated to investigate the plant-microbiome of hydroponic agriculture systems such as the Advanced Plant Habitat (APH) via the use of an on-board mini sequencer. A parallel approach is needed to better understand the effects of additional constraints (e.g., lack of supplies, technology/data delays, radiation, and lunar gravity effects) on the production of crop systems at the Shackleton crater. Ideally, the technology available on the lunar-APH system will mimic the ISS APH and earth APH environmental conditions to potentially identify gravity or radiation driven differences between the parallel hydroponic systems. An alternate growth chamber could use direct or filtered solar radiation for plant growth, but further studies are needed to understand how this might affect plant and plant-microbe systems. Plant-microbe relationships are still poorly understood and the opportunity to study rhizosphere microbiomes in controlled settings, across three gravitational and radiation environments, will prove useful in developing strategies that improve agricultural safety and production.

1:40 p.m. BREAK

1:50 p.m. Foing B. * Kolodziejczyk A. Musilova M. Rogers H. Kerber S. et al.

***Space Biology Experiments During ILEWG EuroMoonMars Campaigns Preparing for Artemis* [#2045] Plant and Plant Enabling Technology**

ILEWG has organised since 1994 ICEUM International Conferences on Exploration & Utilisation of the Moon sessions at EGU, COSPAR, EPSC with community recommendations. At ICEUM13 in 2018 at COSPAR 42nd Assembly in Pasadena, California, recommendations included: - Encourage to consider life sciences experiments on precursor robotic missions - Call for studying opportunities from commercial landers and missions- Noted key aspects of radiation research, health risks, countermeasures, travel to Mars - Recommend a Rational and multi-purpose driven programme - Reiterate the need for protection of environments regarding science, utilisation and ethical considerations, and the establishment of a framework for planetary stewardship .The ILEWG EuroMoonMars programme includes research activities for data analysis, instruments tests and development, field tests in MoonMars analogue, pilot projects , training and hands-on workshops, and outreach activities. EuroMoonMars field campaigns have been have been conducted in ESTEC, EAC, at Utah MDRS station, Eifel, Rio Tinto, Iceland, La Reunion, LunAres &AATC bases in Poland , and HISEAs base in Hawaii. In 2019, the EuroMoonMars IMA-HISEAs (EMMIHS) campaigns were launched. Six persons crew spent two weeks at the Moonbase station performing research relevant to both the Moon and Mars there. The EMMIHS campaigns aim to increase the research and technology testing in order to help humans settle on the Moon and Mars. They support the preparation for Artemis and an actual Moon base. Space biology experiments were conducted during EMMIHS: - Food development and use of crops for air purification and oxygen production. - Experimental research was conducted, to grow crops, from garden cress seeds, sown in soil that resembles the regolith on Mars and the Moon. - Nutritional study concerning crew health, well-being, and social factors with changes in food assortment- Human Factors experiment regarding social and psychological well-being, and contact within the crew and with local/remote support- Medical Well-being of the crew, derived by basic body measurements, such as heart rate, blood pressure, balance, etc…In October 2020, we conducted isolated Moonbase habitat crew simulations at AATC Analog Astronaut Training Centre Poland. A number of space biology experiments (including hydroponics) were also conducted that are relevant for the preparation to Artemis surface mission.

2:00 p.m. Monje O. * Heinse R. Romeyn M. Fritsche R.

***Calibrating Plant Watering System Models with Long-Term Lunar Capillary Data* [#2006] Plant and Plant Enabling Technology**

We propose to collect the first long-term imbibition and moisture hysteresis data from capillary substrates under the influence of partial gravity for testing hydraulic models used to design future sustainable lunar and martian plant growth systems.The originally submitted abstract was peer reviewed and is available at: https://www.hou.usra.edu/meetings/lunarsurface2020/pdf/5065.pdf.

2:10 p.m. McKay C. P. * Kiss J. Z. Bowman R. N. Horne M. Choudhury K.

***Novel Hardware for a Lunar Plant Experiment* [#2008] Plant and Plant Enabling Technology**

We propose an experiment, LPX (Lunar plant growth experiment), on the surface of the Moon that will conduct a fundamental investigation into the response of the plant Arabidopsis to lunar gravity and lunar radiation. For statistical significance, we will include more than 50 seeds. The experiment begins after lunar landing with water added to the seed platform and continues for 10 days or more. The growth of the plants, reaching ~ 1 cm high with typically 3-4 leaves in 10 days, will be monitored by camera and the carbon dioxide in the sealed chamber also will be monitored. The hardware for the LPX is based on proven technology flown on the ISS in Dec 2019 (Kitto et al. 2021, Life Sci. Space Res. in press) and the “Phytofuge” canister for Techshot MVP (Multi-use Variable-gravity Platform) centrifuge – both on ISS now. Both of these systems are TRL 9. This approach will allow identical units to be sent to the Moon and to be flown on ISS - allowing direct comparisons to partial gravity experiments done on the ISS experiment. Germination and growth of Arabidopsis requires temperature range of 20–25°C with the optimum being 22–23°C (Shymanovich and Kiss 2020, Gravit. & Space Res., 8, 1-7). This level of thermal control is a challenge on a small lunar lander and is effectively set by the latitude of the landing site. Given the mass and power limitations on a small lander, and the internal power of the LPX (~ 5W) the landing site needs to be between 73° and 77° ? for which the noon time lunar surface temperatures are +15°C and -3°C (Hurley et al. 2015, Icarus 255,159-163). Within this range the temperature can be set with a small thermostatically-controlled heater These proposed experiments would be the first to grow plants on another planet and would provide important insights in terms of growth of plants on the Moon as part of bioregenerative life support.

2:20 p.m. Singh N. K. * Reed D. Boland E. Elliot J. Gilroy S. et al.
***Sustainable Technologies for Plant Growth in Lunar Systems* [#2043] Plant and Plant Enabling Technology**
Plants are an essential component of the life support system on earth and will be crucial for sustainable human exploration to the Moon, Mars, and Beyond. NASA's interest in growing plants in the space environment led to the development of VEGGIE and Advanced Plant Habitat, currently operational on the Space Station. JPL and Techshot together are developing concepts for sustainable lunar plant growth technologies. The concept focuses on four major goals.•Develop a customized plant growth bioreactor functional at low gravity•Select plant species that use lunar regolith (LR) as the rooting substrate for growth in low gravity•Study the microbial ecosystem of the customized bioreactor by modifying the rhizosphere•Develop a full-scale lunar greenhouse module capable of harnessing the lunar in-situ resources, merging it with aeroponics, vertical gardening, and production of nitrogen-rich microbial biomass. The bioreactor with LR and rhizosphere microbes will be used to determine the interaction of plant-microbe in long-term life support systems. The custom bioreactor developed by the JPL-Techshot team will be suitable for analyzing plant-microbe growth and interaction. It will also help study physiological responses to stimuli encountered during spaceflight environments such as microgravity, low gravity (like for the Moon and Mars), radiation, low nutrient bioavailability, change in soil conductivity, oxygen, CO2, and phenotypic changes. The JPL-Techshot team will develop a robust bioreactor functional under low gravity by using commercially available LR infused with native earth soil microbes to select lunar plant candidates. Indigenous soil microbes aiding plant growth will be identified and quantified using metagenomic sequencing. Simulated LR infused with soil microbes and plants will be periodically analyzed during its growth cycle to assess the plant-microbe interaction. Particular emphasis will be placed on microbes enhancing plant growth factors to the soil (e.g., nitrogen fixation). A comparison with the ground-based 1g experiment will help quantify the changes in low gravity. Lessons from the pilot experiment will be used to develop a full-scale lunar greenhouse module capable of harnessing lunar in-situ resources. The proposed project's development will provide NASA with a sustainable plant growth system for Moon to characterize plant-microbe interaction in LR and directly respond to the Space Biology Decadal Survey Recommendations P2 and P3.

2:30 p.m. Bywaters K. F. * Stoker C. Ricco A. Bergman D. Zacny K.
***Monitoring Microbial Growth on the Lunar Surface in Fluids Containing Lunar Regolith* [#2010] Microbiology**
Intro: Lunar microbial studies are needed to advance our understanding of how conditions of outer space and the stressors of lunar regolith impact microbial growth and survivability. A sustainable lunar base will need in situ resource utilization and microbes could be important due to their different capacities (i.e. oxygenic photosynthesis, potential to extract nutrients and materials from regolith). To understand the effects of the lunar environment on microbial physiology available flight-ready hardware is one of the major challenges. Background: It was thought that microbes are too small and intra-cellularly homogeneous for gravity to have an impact [1]. However, multiple microorganisms have shown altered growth characteristics during space flight relative to ground controls [2-3] including altered rates of growth and/or metabolic activity [4-5]. Furthermore, there is concern about the toxic properties of lunar dust. Studies show that lunar simulants are cytotoxic and genotoxic causing DNA damage and cell death [6]. Microbes have been exposed to lunar simulants; however, simulants do not have the highly reduced and chemically-activated irradiated characteristics, do not contain agglutinates, and lack the sharp, shattered-glass-like morphology of lunar particles [7]. Tech Approach: Lunar Microbiological Experiments Platform (LuMEP) will be a microbial growth-and-analysis instrument capable of being mounted on a CLPS lander. Regolith will be delivered by PlanetVac, which uses high pressure gas to stir up regolith and convey it via transfer tube to the instrument [8]. PlanetVac is scheduled to fly to the Moon in 2023 as part of CLPS and to Phobos in 2024 as part of the MMX mission. LuMEP will mix the regolith with growth media and feed the mix into culture microwells. Growth, morphological, and fluorescence characteristics will be observed microscopically, enabling the enumeration of cells during growth phase and tracking of real-time physical cellular response. References: [1] Pollard, E. (1965) J. Theor. Biol. 8, 113–123 [2] Wang, G. et al. (2006) Acta Astronaut. 58, 264–269 [3] Xiao, Y. et al. (2010) Toxicon 56, 1–7 [4] Padgen, M., et al. (2020) Life Sci Space Res, 24, 18-24 [5] Nicholson, W., Ricco, A., (2020) Life, 10, 1-14 [6] Caston, R. et al. (2018) GeoHealth [7] Park, Y. et al. (2006) Lunar and Planet. Sci Conf, 37, #2193 [8] Spring, J. et al. (2019) IEEE Aerospace Conf., 2-9 March 2019, Big Sky, MT Acknowledgements: Support from NASA Ames IRAD.

2:40 p.m. Granata T. C. * Egli M. Wadsworth J. Ille F. Reattenbacher B.
***Effects of Low Gravity and Cosmic Radiation on Microalgae Growth and Polymer Production* [#2014] Microbiology**
Crewed long-duration space missions and especially sustained human presence on the surface of celestial bodies are linked inevitably to sustainable resources, such as a reliable life support system (e.g. wastewater treatment and reconditioning the air) and availability of raw materials. The logistics necessary to secure the live support and materials for manufacturing, however, increases substantially the farther and longer the crew is travelling in space. Indeed, the ultimate goal to reach in the future is to establish a certain independence of the space-travelers from the earth-bound supply chain, especially for raw manufacturing materials.We propose to reach this goal by implementing a cradle-to-cradle approach via operating on-site, microbial factories consisting of autonomously running photo-bioreactors. Microalgae cultivated in bioreactors can take-up carbon dioxide (CO2) from the atmosphere and release oxygen (O2). Furthermore, microalgae can serve as sources for various biomaterials like proteins, lipids and carbohydrates. Such raw materials can be post-processed to obtain food supplements, oil or fuel, carbon fiber and bioplastic for 3D-printing. But because the concept is based on living cells that respond to low gravity as well as cosmic radiation, as previous studies have shown, the extend of the changes to the extraterrestrial conditions is uncertain. Thus, the aim of the project will be to deploy biological experiments on the lunar surface to determine the long-term effects of low gravity and cosmic radiation, and how it will modify cell growth, biomass production, cell motility, and the cells' biochemical composition. The backbone of the system is a small, modular bioreactor comprising two sections. Section 1 is lit by LEDs and has four, 4 milliliter (ml) growth chambers to cultivate the algae Testraselmis sp.; two chambers are protected from and two exposed to cosmic rays. Section 2 is a chamber for staining cells and the biochemical analyses. The stains will be optical resolved to quantify cell viability, lipids, proteins, and starches. Both chambers will be monitored for temperature, chlorophyll fluorescence, pH (for CO2), optical density (for biomass), dissolved oxygen (O2), and cosmic radiation. An identical system will be used at the ground station for 0g and 1g simulations.

2:50 p.m. Lee J. A. * Boston P. J. Buckner D. Everroad R. C. Ledford S. M. et al.
***SOTERIA: Searching for Organisms Through Equipment Recovery at Impact Areas* [#2021] Microbiology**
All spacecraft sent to the Moon carry viable microorganisms with them. Historical measurements and recent mathematical models predict that even after the effect of space exposure and, in some cases, high-velocity impact, most deliver a bioburden of thousands to millions of cells each to the Moon. While it is widely assumed that no life can withstand the harsh physical conditions of the Moon, it is worth examining whether any of the recently delivered Earth biomass remains viable, given that survivors have been reported from space biology exposure studies from the International Space Station and Apollo era. Because the Moon's surface environment is sterilizing to life, NASA policy has not required the elimination or even the measurement of microbial contamination on lunar space equipment prior to launch. Consequently, contaminated hardware remaining on the moon provides an ideal case study to learn about the outcomes of microbial dispersal on pristine worlds. We have recently reported on a model estimating the bioburden that is likely to remain on spacecraft debris currently on the Moon; results indicate that the interior surfaces of hardware remaining at the lunar south pole may still harbor viable cells or spores. Upcoming human missions of the Artemis program would make sampling and investigation of this hardware possible, offering the first ever impact survival data for refining planetary protection protocols for solar system exploration, as well as unique insight for the field of astrobiology. We propose a two-phased mission where astronauts on the Moon would recover debris from previously crashed spacecraft for return to Earth; later, upon return to terrestrial laboratories, samples could be analyzed for viable life and biosignatures. This sample return mission would be preceded by an imaging mission to obtain high-resolution data on the target sampling site located near the Lunar South Pole. We propose the name of SOTERIA for this planetary protection mission, in honor of the Greek goddess of safety and delivery from harm.

3:00 p.m. Khodadad C. L. * Hummerick M. E. Dixit A. R.
***Exposure to the Lunar Space Environment Influences Microbial and Fungal Microbe Gene Expression and Survival* [#2044] Microbiology**
Astronauts on deep space missions to the Moon and beyond will require fresh, nutritious, safe to eat food supplements to their diet. Missions to the lunar surface will need to be autonomous and rely less on support from Earth and it will be necessary to have microbial monitoring capabilities in place not only for the environment but for the food supplemental resources. Conditions on the lunar surface include higher

radiation levels compared to Earth, where high radiation levels have a negative effect on most higher organisms due to DNA damage from single or double stranded breaks. However, numerous bacteria and fungi possess the ability to survive and reproduce under high radiation levels. This resistance may be due to either the expression of certain genes, the production of protective, intracellular protein molecules and melanin, or both. Microbiome studies of Veggie plant material returned from station have provided us with a characterization of the plant microbiome and a short list of several isolates that have the capability to adapt or survive in the high radiation environment. Potential bacterial candidates (Escherichia coli, Bacillus pumilus, Deinococcus radiodurans, and Pseudomonas aeruginosa) and potential fungal candidates (Exophiala, Aspergillus, Cryptococcus, and Rhodoturula) were selected with the goal of exposing these live cells and/or spores to the radiation conditions on the lunar surface for a pre-determined amount of time without requiring crew handling. The cells may be applied to light weight gel filters or treated coupons which would provide an adequate carbon source for survival and maintenance until return. Radiation levels will be monitored. Return of the samples to Earth will be followed by molecular analysis to determine survivability and include genomic and transcriptomic molecular protocols. Certain genes (i.e. Rad genes or Bdr1 gene-a regulator of gamma radiation in some cells) that provide protection from radiation as well as those genes that are up/down regulated will also be investigated with gene expression studies. Quantitation will be determined using quantitative reverse transcriptase polymerase chain reaction (qRT-PCR). Data will provide information as to the survival rate and isolate the effects and DNA repair mechanism(s) of each organism. This should also provide baseline information on adaptive measures these cells possess and increase our understanding of how lunar radiation might impact a microbiome.

3:10 p.m. *Adjourn*

Thursday, January 21, 2021
LSSW SPACE BIOLOGY: ABSTRACT TALKS DAY 2
Chairs: Kevin Sato and Sharmila Bhattacharya
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9:00 a.m. Kevin Sato *
Welcome

9:05 a.m. Narayanan S. A. * Caldwell J. T. Delp M. D.
Lunar Spaceflight Effects on Gastrointestinal Cardiovascular and Immune Status **[#2037] Vertebrate**
Astronauts on deep space missions to the Moon will face health risks from simultaneous prolonged exposure to a weightless environment and radiation that is more harmful than that found on Earth or during LEO missions. The cardiovascular system has adapted to gravity on Earth. The removal of hydrostatic pressure gradients from exposure to weightlessness has been considered the primary driver of spaceflight-induced circulatory adaptations. The circulation (consisting of arteries, veins, and lymphatic vessels) transports blood and lymph, which contain immune factors. Changes in immune factor distribution can lead to increased susceptibility to infections and inflammatory pathologies, as well as lead to vascular and lymphatic functional adaptations. LEO and Apollo spaceflight missions have been shown to cause immune dysregulation in astronauts, as well as increasing medical risks (e.g., gastroenteritis) of organ beds responsible for maintaining immune tolerance, including the gastrointestinal system. The lymphatics support gastrointestinal structure and function, as well as immune tolerance. However, there is a paucity of data of how the spaceflight environment effects gastrointestinal, as well as lymphatic physiology. This scientific research abstract proposes for the study of the effects of spaceflight during a Lunar mission on gastrointestinal immune state and lymphatic function. There are a number of factors that occur during a deep space mission that cannot be precisely simulated by Earth-based analogs and/or low-Earth orbital platforms. Indeed, study of lymphatic adaptations from a Lunar mission would increase our fundamental knowledge of spaceflight cardiovascular and gastrointestinal system adaptations, as well as highlight any potential risks that astronauts face during Lunar mission through the Artemis program.

9:15 a.m. Mao X. W. * Stanbouly S. Delp M.
Lunar Spaceflight-Induced Effects on Ocular Response and Blood-Retina Barrier Function **[#2024] Vertebrate**
The health risk of flight condition-triggered ocular injury and neurodegeneration has long been a concern. Lunar mission will likely expose the astronauts and experiment payloads to greater radiation levels compared to those encountered on the ISS. These radiation exposures due to galactic cosmic rays (GCRs) pose significant hazard to astronauts and spacecraft. However, knowledge about the susceptibility to low doses of radiation relevant to those that will be encountered during space missions is very limited. This is mostly due to the lack of human epidemiology data from charged particle exposures and the relatively limited number of experimental animal studies from which to extrapolate. The adverse effects of radiation on the retina and retinal vasculature have been reported by multiple investigators who have documented structural, histopathological, and functional alterations in the affected retina after irradiation exposure. Our previous study revealed that exposure to low-dose ionizing radiation induced cellular oxidative damage that may alter retina structure and blood-retina barrier (BRB) integrity. Significant changes in retinal endothelial cells occur at doses as low as 1 cGy. Our data for combined exposure of solar particle event (SPE)-like exposures of proton irradiation and simulated microgravity has shown significant impact of spaceflight condition on retinal endothelial cell survival. Investigation of the short and long-term effects of lunar spaceflight on ocular structure, neurovascular remodeling, BRB function is important for potential risk assessment on developing spaceflight-induced neuro-ocular syndrome and late retinal degeneration associated with deep space travel.

9:25 a.m. Delp M. D. * Narayanan S. A. Caldwell J. T. Mao X. W.
Lunar Spaceflight Effects on Cardiovascular Health **[#2029] Vertebrate**
The human experience with spaceflight has shown that space exploration comes with various health risks. As NASA prepares for manned missions to the Moon, these health risks will rise as travel goes beyond the Earth's protective magnetosphere. The long-term effect of space radiation on cardiovascular health has received little attention until recently. Cucinotta et al. (Life Sci Space Res 10, 2016) estimated that the accumulated radiation exposure of the Apollo lunar astronauts was less than 0.6 Sv. Using meta-analysis of major studies of occupational and environmental radiation exposure, Little et al. (Environ Health Perspect 120, 2012) have

demonstrated elevated circulatory disease risk at even lower doses of less than 0.2 Sv. These risk estimates are also based on low linear energy transfer (LET) radiation exposures, which are known to be less damaging to biological tissue than the high-LET radiation that makes up a portion of the GCR and to which future lunar astronauts will be exposed. The vascular endothelium is an important regulator of vascular tone in arteries, veins and lymphatic vessels, and is particularly sensitive to the harmful effects of radiation. The endothelium provides protection from the development of atherosclerotic plaque in arteries and blood clot formation in veins. This latter feature of the vascular endothelium is particularly relevant for spaceflight since venous thrombosis was recently found to occur in astronauts on long duration missions to the ISS. In addition, vascular endothelial cells make up the blood-brain barrier and blood-retinal barrier, and these endothelial cells in the brain and eyes have been shown to be disrupted by spaceflight in low-Earth orbit. The additional impact of low-dose deep space irradiation with weightlessness on the vascular endothelium could significantly increase adverse short-term and long-term cardiovascular health consequences relative to that during spaceflight in low-Earth orbit. Therefore, the effects of lunar spaceflight on arterial, venous and lymphatic endothelial cells will be vital to our understanding and assessment of cardiovascular health risks associated with deep space lunar travel.

9:35 a.m. Caldwell J. T. * Narayanan S. A. Delp M. D.

Lunar Spaceflight Effects on Internal Jugular Vein Physiology **[#2035] Vertebrate**

Future missions to the Moon pose unique health risks to Astronauts due to extended periods of weightlessness and radiation exposure, the singular and combined effects of which are incompletely understood. Spaceflight-induced weightlessness causes a passive upward fluid shift, leading to cardiovascular disturbances that can include increased intracranial pressure and impaired cerebrovascular hemodynamics. Present evidence suggests that changes in cephalic venous circulation (i.e., venous congestion) impair cerebral venous outflow, reducing cerebrovascular function. Recent work by Marshall-Goebel et al. (AMA Netw Open. 2019) have demonstrated that six of the eleven crewmembers had stagnant or retrograde flow in the internal jugular vein on a long duration mission to the ISS. Importantly, two crew members on the ISS mission that presented stagnant venous flow were diagnosed with a venous thrombosis in the internal jugular vein, the cause of which is currently unknown. The impairment in venous return could negatively impact endothelial function. The endothelium is essential in protecting from clot formation and maintaining vasomotor properties that regulate blood flow. The formation of the venous thrombosis may have resulted from structural or functional maladaptations of endothelial cells lining the jugular vein; recent results from mice flown on the ISS support this suggestion. However, investigations targeting the endothelium of the internal jugular vein, as well as deep veins in the legs, during extended weightlessness with concurrent deep space radiation are lacking. Therefore, understanding changes in the internal jugular vein endothelial cell lining during deep space missions to the Moon should be a top priority given the potential health consequences of venous thrombosis.

9:45 a.m. Cromer W. E. * Zawieja D. C.

Role of Lymph Node Integrity in Regional GI Function During Spaceflight **[#2030] Vertebrate**

The Gastrointestinal tract is a complex organ system that is highly susceptible to both internal and external factors which can affect it’s function. It houses the densest and most complex microbiome of the body which itself acts as an extension of the digestive, immune and endocrine system. Additionally, there are the greatest number of resident immune cells in the tissues of the GI tract compared to any other organ system. These two groups of cells cross regulate one another under normal circumstances to maintain tolerance of the normal gut flora while still being able to mount an immune response to pathogenic members of the microbiome. At the heart of this interaction is the regional lymphatic system and lymph nodes of the GI tract where peripheral regulation of tolerance and adaptive immunity occurs. The nodes are specialized structures that are derived from and are fed by lymphatic vessels in the intestinal tissue who themselves have to be able to adapt to wide changes in the content and volume of the lymph produced in the tissue. The inner surface of both the node and vessels are lined by lymphatic endothelial cells which help regulate the immune response (node and vessel) and transport of lymph (vessel). We have preliminary data from lymph nodes flown in LEO that show signs of mild to severe lymphatic endothelial dysfunction and immune dysfunction. The lymphatic endothelium of the node acts as an antigen bank for both self and foreign antigens and can present them directly to cells within the node or can transfer them to antigen presenting cells which can carry the antigen to different regions of the node. The nodal endothelium also produces a number of factors (e.g. IL-7) that maintain immune cell tolerance and polarization with in the node.Failure of the nodal endothelium in these

roles could be responsible some of the immune dysfunction we have noted in the Gi tract as well as have impacts on tolerance of the microbiome which is also altered in spaceflight. If this is occurring in LEO where radiation levels are relatively speaking low and there are no other factors at play (like regolith dust which would act like talc [Chess, 1950]) we are concerned that there may be even more severe alterations to the GI lymphatic system in the lunar environment which may exacerbate dysfunctions in both the immune system and microbiome. This opportunity would provide us with samples that are impossible to generate in terrestrial environments.

9:55 a.m. Etheridge T. Vanapalli S. Holt J. Szewczyk N. J. *
***Worms on the Moon* [#2011] Invertebrate**
The microscopic nematode C. elegans is one of a number of standard laboratory animals considered to be a model organism for genetic and genomic research on Earth. Landmark work with C. elegans has given us the tools needed to sequence the human genome, the ability to follow individual fluorescent proteins in living creatures, the ability to silence gene expression, and an understanding of how cells intentionally kill themselves in response to adverse conditions. As a model organism, C. elegans can be used to understand how diseases are caused and can be treated, for example muscular dystrophy, and can be used to understand how the environment influences health, for example spaceflight.To date, the study of worms in space has yielded important information on the adaptation to spaceflight. Early studies revealed that increased rates of mutation in space were directly attributable to exposure to radiation alone vs. exposure to microgravity or combined exposure. Subsequent studies have shown that development, programmed cell death, and the ability to silence gene expression are all more or less normal in worms in space. Similarly, worms have been successfully grown on the ISS for 24 generations, over 6 months, without major alterations in health; this is long enough to send worms to Mars on a short transit flight. Subtle changes in worms in space include alterations in telomeres and in mitochondrial gene expression, findings recently confirmed in astronauts as part of the Twins study.In addition to continuing to study the causal molecular pathways for gene expression alteration in response to spaceflight and pharmacologic interventions to prevent gene expression alteration in space, we have been developing tools for studying worms on free-fliers and/or interplanetary missions. One such tool is the Deep Space Petri Pod (DSSP), which is essentially 6 wells of dimensions similar to 96 well tissue culture plates. The DSSP enables visual monitoring of worm health in space. Other tools include the NemaFlex for measuring worm strength and the NemaLife for measuring worm lifespan and healthspan.We believe that just as worms in space have provided valuable information about human health in space, so too will worms on the Moon. Key challenges for such experiments are similar to those discussed for other free-flying biology missions such as BioSentinel.

10:05 a.m. O'Rourke A. E. *
***A Lunar Ground Truth of Microbes that are Integral to Sustaining Bioregenerative Life Support Systems* [#2020] Microbiology**
A cis-lunar outpost such as Gateway or a Mars transit vehicle will use a semi-closed supplemental bioregenerative life support system (BLSS) with components adapted to withstand microgravity and high levels of radiation. A moon habitat will likely exist under partial gravity conditions and sustained levels of high radiation as a semi-closed loop system able to get resources from Earth via Gateway. Additionally, the moon will act as a life support testbed for Mars habitat operations and could employ various components of in situ resource utilization (ISRU). One of the longest running BLSS projects to date is that of the European Space Agency’s MELiSSA (Micro Ecological Life Support System Alternative) project, a circular life support system, established to gain knowledge on regenerative systems aimed at the highest degree of autonomy to produce food, water and oxygen from mission wastes. This setup has evaluated the use of microbial compartments and a higher plant compartment to carry out the necessary life support functions to support crew. Such compartments utilize thermophilic anaerobes to break down human and inedible plant wastes, photoheterotrophic bacteria that can further metabolize volatile fatty acids, nitrifying bacteria that can convert ammonium to plant and microalgae available nitrates, and photoautotrophic bacteria and higher plants which will convert carbon dioxide to oxygen, purify water, and provide food for human consumption. This being one of the most advanced BLSS models to date -aside from the Yuegong-1, Chinese Lunar Palace- with the most defined compartment composition, and the assumption that other BLSSs will build upon such models, it becomes relevant to study the effects of the lunar environment upon the microbes that are integral to a BLSS. In ramping up to advanced stage BLSS systems, relatively simple experiments can be conducted on the planned Artemis missions using continuous culturing and samplings of microbes. Such monocultures and

mixed cultures can be intermittently sequenced for mutational monitoring and chemical analysis can be conducted to assess for the sustained ability to carry out hallmark biochemical processes efficiently. A suite of microbes should be assessed, prioritizing those with the dual capacity to be utilized in an BLSS and the ability to biochemically facilitate ISRU goals, such as the ability to transform the biogeochemistry of Moon or Martian regolith into materials that can support crop growth or extract elements of industrial significance such as iron.

10:15 a.m. BREAK

10:25 a.m. Santa Maria S. R. * Liddell L. C. Young Z. Ricco A. J. McIntosh D.
***Lunar BioSensor: An Autonomous Instrument to Study the Effects of the Lunar Environment on Biological Organisms* [#2001] Enabling Technology**
One of the major challenges to long-duration space travel and habitation in deep space is an in-depth understanding of the biological effects of space radiation, often convoluted by the impact of reduced gravity. Nonetheless, due to the near impossibility of simulating prolonged exposure to these combined effects in terrestrial facilities, actual missions are needed to characterize the radiobiological hazards of this environment.NASA Ames has been the leader in developing autonomous bio nanosatellites to address strategic knowledge gaps about the effects of space travel on biological organisms, including GeneSat, PharmaSat, EcAMSat, and BioSentinel. BioSentinel will be the first interplanetary bio nanosatellite or CubeSat to study the biological response to space radiation outside Low Earth Orbit (LEO). BioSentinel is an autonomous platform able to support biology and to investigate the effects of space radiation on a model organism in interplanetary deep space. It will fly onboard NASA's Artemis-1, from which it will be deployed on a lunar fly-by trajectory and into a heliocentric orbit.The BioSentinel nanosatellite, a 6U deep space CubeSat (1U = 10-cm cube), will measure the DNA damage and response to ambient space radiation in a model biological organism, the budding yeast S. cerevisiae, which will be compared to information provided by an onboard physical radiation sensor and to data obtained in LEO (on the ISS) and on Earth. Even though the primary objective of the mission is to develop an autonomous spacecraft capable of conducting biological experiments in deep space, the 4U BioSensor science payload contained within the 6U free-flyer is an adaptable instrument platform that can perform biological measurements with different microorganisms and in multiple space environments, including the ISS, lunar gateway, and on the surface of the Moon. The proposed 4U instrument will leverage the payload design of the 6U free-flyer, utilizing the lunar lander or vehicle for power and data relay. Thus, nanosatellites like BioSentinel (and Lunar BioSensor) can be used to study the effects of both reduced gravity and space radiation and can house different bio organisms to answer specific science questions. In addition to their flexibility, nanosatellites also provide a low-cost alternative to more complex and larger missions, and require minimal crew support, if any.

10:35 a.m. Wagner E. B. *
***Using New Shepard as a Lunar-G Testbed* [#2002] Enabling Technology**
Blue Origin is developing a new Partial-G capability for the New Shepard suborbital system. Using thecapsule's reaction control system (RCS) to spin up the full capsule, we can tune a mission forapproximately two minutes of variable gravity exposure at a radius that minimizes Coriolis effects compared to drop tower and sounding rocket alternatives. Such a mission provides opportunities for studying Partial-G biological and physical science phenomenon, as well as for maturing a wide range of planetary surface technologies, including significant ties to exploration sustainability, such as ISRU and ECLSS. New Shepard consists of a propulsion module (PM) and separable Crew Capsule (CC) carrying up to 36 payload Lockers, or ultimately up to six astronauts above the Karman Line (100 km, 328kft) before returning safely to Earth. Each payload stack is a modular system supported by its own power, data recording, command, and control services to experiments, supporting a wide range of payload needs. An initial Lunar-G (11 rpm) mission is in its planning phases, and offers access to industry-leading durations of continuous one-sixth G for collecting preliminary data, conducting targeted investigations, and reducing future mission risk. We will discuss opportunities for maturing space biology hardware for deployment on the lunar surface, as well as for examining G-transitions and identifying biological G-sensing thresholds.

10:45 a.m. Howard R. L. Jr. *

***A Notional Configuration and Discussion of a Lunar Surface Space Biology Laboratory* [#2012] Enabling Technology**

As NASA develops and refines concepts for a sustainable return to the Moon it is important to generate concepts for a space biology laboratory. This requires a meeting of minds between the space architecture and space biology communities. In many surface architecture teams dating back to the Constellation program there has often been a tendency to equate science with EVA-based geology, to the point that some early habitat concepts have entirely overlooked space biology capabilities, or assumed that any life science needs were fully contained within the crew medical outfitting. Space architecture faces the chicken and egg problem of not knowing how much space is needed for space biology or how much space in the habitat can be made available for space biology. It is important to make proper provision for science capabilities as early as possible in the design process, rather than attempt to wedge them in after the fact. Discussion generated through this session may at least help to establish some reasonable starting points for future iteration. During the Constellation program, the Optimizing Science & Exploration Working Group (OSEWG) developed an extensive listing of science equipment in a variety of categories, including space biology. From a long-term human habitability perspective, there are additional architecture questions that space biology may also be able to address, including expanded food production and comparative research involving different low gravity levels. These questions have been combined with OSEWG science instrument recommendations to create a notional lunar Space Biology Laboratory. Following a review of a CAD model of the laboratory's architectural configuration, individual laboratory components will be described including stowage elements, utilities elements, self-contained payloads, instruments shared across multiple payloads, computing and display systems, and work surfaces. This notional laboratory will then be used as a platform to discuss a number of open questions with architectural impacts including crew member human performance, basic architectural layout, adjacencies and separation within the habitat, consumables throughput, survivability of live payloads during transit and uncrewed periods, and utilities. A forward path to iterate Space Biology Laboratory development will be discussed including its accommodation with other science laboratory and additional utilization capabilities within NASA reference habitats.

10:55 a.m. Sun S. C. * Karouia F. Lera M. P. Parra M. P. Ray H. E. et al.

***Lunar Life Sciences Payload Assessment* [#2032] Enabling Technology**

A summary of the types of biological payloads that should be flown on CLPS and HLS to address a range of basic and applied research questions, based on an assessment of over 60 payload systems that have flown or are being developed.The originally submitted abstract was peer reviewed and is available at: https://www.hou.usra.edu/meetings/lunarsurface2020/pdf/5077.pdf.

11:05 a.m. Riedo A. * de Koning C. Grimaudo V. Ligterink N. F. W. Keresztes Schmidt P. et al.

***Laser Ablation/Desorption Ionization Mass Spectrometry for In-Situ Characterization of Biomarkers Experiments* [#2034] Enabling Technology**

Laboratory-sized instrumentation typically used in life science for characterization of e.g., biological systems cannot be applied in space exploration missions due to the limited resources available such as volume, power, and mass. Moreover, the return of, e.g., biological samples to Earth after concluding experimentation on the lunar surface is questionable because of the high return-costs to Earth, and maintaining their state. Therefore, simple and sensitive instrumentation is required on-site that will allow, e.g., to track chemical compositional changes of long-term experiments in situ. In our contribution we present a miniature reflectron-type time-of-flight laser ablation/desorption mass spectrometer (LIMS, LD-MS) that allows the element/isotope (ablation mode) and molecule (desorption mode) analysis of solids or analytes of interest. The operation of such a system is both robust and simple. The miniature mass analyzer (160 mm x Ø 60 mm) is coupled to a pulsed laser system that allows the ablation or desorption and ionization of sample material. A beam guiding system is used to guide laser pulses from the laser system to the sample surface by focusing the laser beam through the mass analyzer to spot-sizes below 30 µm in diameter. In our contribution, we will address the two different operation modes, the ablation and desorption mode, by discussing measurement campaigns conducted on different samples and analytes. For ablation mode, we will present measurements conducted on solids containing e.g., micrometer-sized fossil structures [1] or single microbes [2], demonstrating that e.g., 2D to 3D element imaging can be conducted, even allowing the analysis of single microbes. For desorption mode, we will present recent studies conducted on amino acids, which are important biomarkers in the context of astrobiology. In ablation mode studies, we reach detection sensitivities for elements and isotopes

at abundances of ppm and sub-ppm level, while for desorption campaigns we routinely reach sensitivities for biomolecules at the few fmol mm?2 [3]. These studies demonstrate that our Laser Ablation/Desorption Mass Spectrometric system can be used for various in-situ tasks and that its operation on-site on the lunar surface would be beneficial for e.g., on-site biological experiments.[1] R. Wiesendanger et al. Astrobiol., 18, 2018, 1071–1080. [2] A. Riedo et al., Astrobiol., 20, 2020, 1224–1235. [3] N.F.W. Ligterink et al., Nature Sci. Rep., 10, 2020, 9641.

11:15 a.m. Madzunkov S. Fry D. Nikolic D. * Simcic J. Raines J. et al.
***Lunar CubeSat Mass Spectrometer with Linear Energy Transfer Spectrometer for Lunar Exosphere Investigations* [#2004] Enabling Technology**
Delivered by comets and asteroids, organic molecules preserved in permanently shadowed lunar craters hold invaluable information on processing the organic material in interplanetary space [1]. NRC report [2] calls for a network of surface mass spectrometers to monitor volatiles' poleward migration. To this end, JPL's Lunar CubeSat Mass Spectrometer (LCMS) and JSC's Linear Energy Transfer Spectrometer (LETS) are being combined into a single suite with shared power and Command & Data Handling electronics.The LCMS/LETS suite will address a longstanding lunar science goal [3-6] to understand Volatile Chemical Compounds (VCC) composition sputtered at the lunar surface and will be ready for integration with a Lunar Commercial Lander platform by the March 2023 timeframe.LCMS is a Quadrupole Ion Trap based Mass Spectrometer (QITMS), currently being matured to a TRL6 under the recent DALI award.With mass (7 kg), power (24 W), sensitivity (0.003 counts/cm3/sec), and precision (0.5% for noble gas isotope ratios over 24 hours [7]), LCMS is capable of tandem MS [8] of complex organic species for astrobiology-focused investigations.LETS is a TRL6 radiation detector with a minimum threshold of 5 keV, developed at CERN by the Medipix2 collaboration for particle tracking at the CERN Large Hadron Collider. The 2cm2 sensor chip is a 256 x 256 energy measuring pixel array that behaves like a digital camera for the traversing radiation particle tracks analyzed in real-time using algorithms onboard the LETS to provide LET spectra and dose rates. The array's acquisition time is varied dynamically by the LETS software between 10 seconds and 10 ms to allow for the measurement of changing and intense radiation fields, such as those encountered during particle belt traversals and SEP events.LETS will make the first radiation measurements on the lunar surface, addressing critical Lunar Human Exploration Strategic Knowledge Gaps (SKG) and helping pave the way for long-term human exploration by determining the lunar surface's radiation environment. References:[1] DOI:10.1016/B978-0-12-415845-0.00025-6[2] DOI:10.17226/11954[3] DOI:10.17226/13117[4] https://www.lpi.usra.edu/leag/reports/ASM-SAT-Report-final.pdf[5] https://www.nasa.gov/sites/default/files/atoms/files/leag-gap-review-sat-2016.pdf[6] http://www.archive.org/download/thelunarexplorationroadmap/Summary%20of%20the%20LER.pdf[7] DOI:10.1021/jasms.8b04662[8] DOI:10.1089/ast.2018.1961.

11:25 a.m. Rask J. * Boston P. J.
***Chemical Reactivity of In-Situ Lunar Dust for Biotoxicity Assessment* [#2027] Lunar Environment**
How does the chemical reactivity of in-situ lunar dust compare to Apollo samples currently stored in curation facilities here on Earth? Essential investigations of this question will help us to further mitigate exploration risks for future human explorers on the Moon and will also provide critical information for astrobiologists and space biologists using the Moon for scientific inquiry.Apollo 14 dust biotoxicity studies, carried out by the NASA Lunar Airborne Dust Toxicity Assessment Group (LADTAG), included numerous cellular and animal experiments. Intratracheal instillation and inhalation studies in rats both showed Apollo 14 dust to be intermediate in toxicity compared to low-tox titanium dusts and high-tox quartz dusts of similar particle sizes. The collective results were used in models to establish a safe exposure limit for astronauts. Although LADTAG took extensive steps to preserve what chemical reactivity may still have existed in the samples, it is simply unknown if they possessed true in-situ chemical reactivity or if that reactivity has decayed. Initial gas loss on collection and other alterations, and even intermittent exposure to Earth-normal conditions during subsequent decades of handling, obscure a forensic reconstruction of the initial state.Because a mineral dust's chemical reactivity influences its biotoxicity, researchers have developed methods to "activate" lunar dust and simulants. Past studies that modeled impact processes and radiation in the lunar environment suggest that in-situ lunar dust is likely to be more chemically reactive than Earth-exposed samples. Because of these results, in-situ measurements are warranted. Since the lunar surface is heterogeneous, dust biotoxicity is expected to vary from site to site due to particle size, mineralogy, physical characteristics, degree of space weathering, and chemical reactivity. This circumstance dictates dust assessments at a suite of lunar sites enabled by CLPS opportunities.Dose, location, and duration of particle exposure will also affect biological responses. In-situ

chemical reactivity measurements can inform cross-cutting collaborative research campaigns such as astrobiology studies examining regolith interactions with organisms and its ability to preserve chemical and structural biomarkers, as well as space biology investigations that examine regolith-microbe interactions relating to life support systems, plant growth, biomining, and development of regolith biocomposites.

11:35 a.m. Looper M. D. * Ferrone K. L. Mazur J. E. Blake J. B. Spence H. E. et al.
Observations of Cosmic-Ray Radiation Effects Near the Moon Over a Complete Solar Cycle by LRO/CRaTER **[#2038] Lunar Environment**
The Cosmic Ray Telescope for the Effects of Radiation (CRaTER) has been measuring energetic-particle radiation aboard the Lunar Reconnaissance Orbiter (LRO) since 2009. Unlike many spaceborne radiation sensors, CRaTER is mainly designed not to measure the spectra of primary energetic particles arriving from space but rather to measure the effects of that radiation on shielded targets. To that end, the sensor incorporates two large pieces of Tissue Equivalent Plastic (TEP) in its detector stack to replicate the effects of an astronaut's soft tissue on radiation passing through his or her body to radiation-sensitive organs like bone marrow.We will present an overview of the measurements CRaTER has made during a complete 11-year cycle of solar activity to date, from the historically deep solar minimum at the start of the mission through maximum and into a new minimum, now ending as Cycle 25 ramps up. These measurements include the variations of the Linear Energy Transfer (LET) due to the changing spectrum of galactic cosmic rays (GCRs) as observed over the solar cycle. The sensor measures energy deposit in silicon, and based on these observations we find that the intensity of the bulk of the GCR population is elevated by 6% as of late 2020 over the already historically-high values seen in the previous solar minimum. We will present the changing effective dose derived from the observed LET spectrum, and will relate that to astronaut health risks over various mission durations undertaken at different parts of the solar cycle.

11:45 a.m. BREAK

Thursday, January 21, 2021
LSSW SPACE BIOLOGY: BREAK OUT SESSIONS DAY 2
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11:55 a.m.	Kevin Sato * *Goals and Questions for Break Out Sessions*
12:05 p.m.	BREAK
12:10 p.m.	*Break Out Rooms:* *Group A — Vertebrate (Robin Elgart)* *Group B — Plant (Gioia Massa)* *Group E — Invertebrate (Jamie Foster)*
1:10 p.m.	*Breakout Rooms:* *Group C — Vertebrate (Marianne Sowa)* *Group D — Plant (Howard Levine)* *Group F — Invertebrate Lucie Poulet)*
2:10 p.m.	BREAK
2:20 p.m.	*Break Out Rooms:* *Group G — Microbiology (Tara Ruttley)* *Group I — Cell Biology Systems (Jennifer Buchli)*
3:20 p.m.	*Break Out Rooms:* *Group H — Microbiology (Louis Stodieck)* *Group J — Cell Biology Systems (Lisa Carnell)*
4:20 p.m.	Sharmila Bhattacharya * *Workshop Wrap-Up*
4:30 p.m.	*Adjourn*

LSSW SPACE BIOLOGY: POSTER PRESENTATIONS

[View 5-minute pre-recorded poster presentations]

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Kolodziejczyk A. M.

***Development of Kombucha 3D Printing for a Deep-Space Mission* [#2015] Enabling Technology**

Kombucha is a symbiotic bacteria and yeast multispecies consortium producing the most abundant polymer on Earth - bacterial cellulose. There are many advantages of bacterial cellulose that are widely utilized in medicine, material science, food industry and waste management.Recent studies on kombucha in space revealed a new promising application for this biomaterial in life support systems for deep-space missions [1,2,3]. Analog ground studies with lunar regolith simulant revealed sustainable kombucha cultures able to absorb minerals from the lunar simulant soil [4]. The biofilm produced by acidic bacteria protects kombucha cultures against high temperatures and radiation, however kombucha cellulose growth in space is yet to be tested. Authors hypothesise that microgravity environment could disturb the polymerization process which occurs in natural conditions.A solution to this problem might be additive manufacturing, also known as 3D printing technology. It will enable bacterial cellulose growth on demand with control over shape, thickness, colour, and hydration. Recently, additive manufacturing has become more popular due to the ability to fabricate complex, customised structures using a variety of materials [5]. Although the technology is most popular in aerospace and medical industries, 3D printing with kombucha has already been developed for bandage production [6]. In this paper, the authors further improve the technique of 3D printing with kombucha for promising space applications.Bibliography:[1]https://www.esa.int/ScienceExploration/HumanandRoboticExploration/Futura/ExposuretospaceandMars[2] Podolich O. et.al., (2016). The First Space-Related Study of a Kombucha Multimicrobial Cellulose-Forming Community: Preparatory Laboratory Experiments. Origins of Life andEvolution of Biospheres. 47. 10.1007/s11084-016-9483-4.[3] Kolodziejczyk et al., (2018). Bacterial cellulose for clothes production in space using kombucha microbial consortium. IAC-18,A1,7,15,x45657.[4]http://www.esa.int/ScienceExploration/HumanandRoboticExploration/Research/SpaceKombuchainthesearchf orlifeanditsorigin[5] R. D'Aveni, (2015). The 3-D printing revolution. Harv. Bus. Rev., vol. 93, no. 5, pp.40–48[6] Kanjou M et al., (2019). 3-D Print Celulose Nanoskin: Future Diabetic wound Healing.JBNB vol.10, 4. https://m.scirp.org/papers/95750.

Lagiewka K.   Kolodziejczyk A. M.   Harasymczuk M. M.   Komenda K.

***Testing New Procedures Increasing Biocontamination Control by Analysis of Microbial Ecology in the Analog Space Habitat* [#2017] Enabling Technology**

Background: The safety and success of the human analog missions within the isolation in the habitat is determined by reduction to minimum and close monitoring of the number of detrimental microorganisms associated with the habitat. Human occupants inevitably constitute key and critical components as they host an intricate microbiome consisting of numerous microorganisms that harbor, transport, and disperse pathogens and other microorganisms. The identification and analysis of the habitat microbial contaminants and their interactions with human occupants' microbes ecosystems is critical to determine the potential biocontamination and corrosion risks for the space habitat inhabitants and the astronaut crews.Methods: The project seeks to characterize and monitor microorganisms that develop and live in the analog space habitat and determine their correlation with the presence of human occupants in terms of potential microbial induced corrosion (MIC)/ biocontamination. It focuses on analysis of the microbe community structures that are cultivable and viable on different types of surfaces and of those living on/in humans.Results: The results determine the microbe community structure by surface type, the astronaut teams' microbiome and pattern that will enable to analyse and describe the habitat-human microbe ecosystem interaction. The results expect to show the impact of those interactions on development of the microbial contaminants by measuring their concentration and observing the potential creation of new microbes.Conclusions: Based on collected and processed data we defined the potential risks of contamination/corrosion. Consequently adequate standard operating procedures were tested and improved the habitat to reduce contamination risks and to increase protection and safety of humans in isolation and 'space habitat livings.'

Komenda K.   Kolodziejczyk A. M.   Harasymczuk M. M.

***Analysis of CO2 Reduction by Algae Multiconsortia Bioreactors in the Lunar Analog Space Habitat* [#2018] Enabling Technology**

Algae are the most widespread oxygen producers in the world. They are also resistant to environmental changes, easy to breed and they effectively reduce CO2. In confined and small spaces, the increased amount of CO2 generates a potential risk for the crew. Three types of microalgae consortia were used in the experiment. Arthrospira plantita, Chlorella, Spirulina,Synechocystis spp. were the most dominant algae species selected for this study. The efficiency of CO2 reduction

was investigated using random positioning machines simulating lunar gravity as a function of time by placing algae consortia in chambers of various volumes in a sealed container. The algae were saturated with the external habitat air rich in CO2. Environmental sensors were continuously collecting data logs both from input and output of the assembly with resolution of 5 min. The volume of live algae needed for effective reduction of CO2 concentration in a small, isolated room was determined experimentally and computationally.Obtained results were used to estimate the overall quantity of microalgae consortia sufficient for a supportive role in the ecology of the closed spaces. We characterised risks and costs related with implementation of this biological method.

Ortega-Hernandez J. M.   Pla-Garcia J.   Martinez-Frias J.   Sanchez-Rodriguez E.   Hernandez-Narvaez J.
***Green Moon Project: Encapsulated and Pressurized Habitat for Plants on the Moon (Habitability and Space Agriculture)* [#2025] Enabling Technology**
With multiple human space missions projected to nearby planetary bodies for the next few years, humanity will become an interplanetary species and must be sustainable. Humans traveling to the Moon, Mars, as well as other planetary bodies will have to grow plants for food. In this way, they will be able to reduce the weight of their trip by being able to use in situ resources (ISRU). The cultivation will allow to take the first step to establish the future human bases on the lunar or Martian surface; it is a need that will make these missions sustainable.Understanding how the growth of plants would be like under the conditions of gravity and radiation that can be found on the Moon is essential before starting to establish future human there. In addition to generating food for the astronauts, thanks to the photosynthesis carried out by plants, they will reduce carbon dioxide and they will generate oxygen.Green Moon Project combines planetary geology, plant biology and aerospace engineering in order to know everything necessary to support space agriculture, as well as the habitability of future manned missions to the Moon or Mars. In this way, the lava tubes are very important in the project as they help protect from cosmic radiation. For this reason, the island of Lanzarote, of volcanic origin, becomes a natural laboratory where to test with rocky substrate similar to that which could be found on the Moon or Mars. From a plant biological perspective, horticultural crops are essential as they provide nutrients, as well as vitamins to humans who travel to the Moon, Mars and beyond. The component of aerospace engineering is seen in the capsule or small space greenhouse within which the cultivation takes place.The encapsulated instrument where the crop will take place (in a first phase) will be made of a series of sensors for carbon dioxide, oxygen, humidity, luminosity, temperature, radiation, as well as a multispectral camera to take images; the germination of the seed and subsequent growth of the plant stem. Green Moon Project has the support of the Spanish Network of Planetology and Astrobiology (REDESPA), the Institute of Geosciences of Spain (IGEO), the Cabildo de Lanzarote, as well as the UNESCO Geopark of Lanzarote. In September 2019, Green Moon Project signed a collaboration agreement with the Chinese Space Exploration Center (COSE) of Chongqing University, the same group that managed to plant the first cotton plant on the Moon in January 2019.

Tompkins D. T.
***Combined Dosimetry and Materiel Testing to Support Activity and Health* [#2028] Enabling Technology**
Lunar temporal radiation has recently been surface studied with German Aerospace Center (DLR) Lunar Lander Neutron and Dosimetry (LND). To further identify and close knowledge gaps associated with radiation, crew activities, and safety it is proposed to include the study of multi material multi spectrum assay in conjunction with radiation dosimetry. Particularly hydrocarbon polymers and polymer regolith combinations to assess radiation mitigation, secondary radiation, ultra-violet mitigation, and thermal cycling. Particular attention to additive manufactured materials with novel layering profiles and automatic temporal threshold testing with burst disk methodology to simplify physical property testing. An in-situ multispectrum material assay can best be performed on lunar surface as temporal multispectrum data is incomplete and not currently achievable in LEO or Earth analogs.

Gifford S. E. G.
***Continuous Physical Rehabilitation in Variable Gravity Fields: The Lunar Surface as a Test Bed* [#2042] Enabling Technology**
On Earth, rehabilitation medicine is a continuous fight against gravity; the moment we leave the planet, that dynamic reverses. For the past century, rehabilitation physicians and therapists have optimized human performance of daily activities and high performance tasks using assistive devices, orthotics, prosthetics, and other functional modifications. After twenty years of continuous habitation on the International Space Station, the functional modifications required for optimized performance in microgravity are somewhat understood, as are the limitations of the human body to fully adapt to that environment. Little is known about the functional modifications required to carry out continual activities of daily living - walking, bathing, cleaning, cooking, etc - or long-term operational research and planetary exploration at gravity fields between 1g and microgravity. The lunar surface is the most accessible and, likely, most cost-effective location for a thorough study of the effect of partial gravity fields on basic human function. By studying the rehabilitation techniques

required to optimize activities of daily living, maintain a minimum level of fitness, and safely reach peak performance of occupational duties on the lunar surface, we will begin to define not only the design requirements of future lunar operations, but all future planetary operations and artificial gravity requirements for deep space transits between gravity fields. In this review, we will discuss what is known about lunar surface operations from a functional standpoint and approaches for using the lunar surface as a test bed for functional optimization, including potential exercise countermeasures for imparting the ground reaction forces and other resistance techniques required to safely and effectively maintain the muscles and bones of basic ambulation.

Tompkins D. V.

***Lunar Plastics — Full-Spectrum Material Assay and Radiation Dosimetry* [#2046] Enabling Technology**

Hydrocarbon polymers and polymer-regolith combinations promise to play a growing role in architecture for sustained human presence in space, including landing infrastructure, disposable airlock seal covers for dust mitigation, spacesuit components, habitats, and greenhouses. Prior work has identified carbon dioxide from human exhalation and trash to provide tons of plastic per year. Hydrocarbon plastics with low atomic weight composition have been identified and tested to show a reduced secondary radiation profile. To identify and close knowledge gaps associated with the employment of these materials on the Lunar surface, we propose a full-spectrum material assay and radiation dosimetry across leading polymers and layering profiles.Specific areas of interest may include radiation mitigation, secondary radiation, ultra-violet mitigation, thermal cycling, and temporal threshold testing, which may be implemented in a low-mass, low-complexity design. Further designs or existing hardware platforms may be suggested by the LSSW community.Particular attention can be given to additive manufactured materials with layering profiles and automatic temporal threshold testing with burst disk methodology to simplify physical property testing. An in-situ multispectrum material assay can best be performed on the Lunar surface as temporal multispectrum data is incomplete. This data will support infrastructure development that enables scientific exploration and close knowledge gaps associated with human health and safety. To enable new possibilities of sustainable space exploration and to ensure mission success, we propose a concept to analyze materials with wide ranging applications. On-demand 3D printing will require a filament of suitable performance. Ultimately, filament can be transported to the lunar surface, though in-situ production would reduce cost and provide an enabling capability. Several polymers have been discussed using in-situ manufacturing capabilities. Collection of presented KPIs on polymer and layering profiles would accelerate efforts to design, test, and build hardware for Lunar missions, and is not possible to acquire in LEO or Earth analog.

Biswal M M K. M.Sc Das N B. B.Sc Annavarapu R N. Ph.D

***Biological Risks and Its Implications for Crewed Interplanetary Missions* [#2013] Space Biology**

In this paper, we have emphasized the major space challenges such as microgravity, space radiation and temperature, vacuum environment, biowastes, habitat and life support system, improper sleep patterns, food preservation, psychological issues and nuclear hazards. In addition to this, we have discussed the biological risks associated with these challenges along with its countermeasures. Our analysis is based on the study and perspective of a crewed mission to Moon, Mars and beyond. Further, the bio-risks highlighted here are the effect of osteoporosis, abnormal vision, orthostatic hypo or hypertension, fluid distribution, changes in brain positions due to microgravity; prolonged cancer, sterility, cataracts, cardiovascular disease, acute radiation syndrome due to radiation; bubble formation and physical damage due to vacuum environment; the effect of hypothermia and frost formation due to low space temperature; oxygen and breathing-related issues due to challenging habitation; damage of circadian rhythm, sleep deprivation and metabolic disorder due to improper illumination and sleep patterns; food poisoning, growth of fresh fruits and vegetables and their impact on psychological health; and the effect of nuclear radiation in case of nuclear propulsion systems. Furthermore, the study shows effective countermeasures as artificial gravity and regular exercise for microgravity, fabrication of materials using polyethylene and hydrides to shield from radiation, proper disposal procedure using anaerobic digester for bio-wastes, a light sensor to induce sleep thereby generating illumination environment, and growth of fresh fruits and vegetables aboard space vehicle to improve psychological health issues.

Kolodziejczyk A. M. Harasymczuk M. M. Gorecki I. Zrebiec B.

***Comparative Analysis of Mass Loss, Digestion, and Aggression in Cockroaches Exposed to Sunlight Simulator Lighting System in Analog Habitat Environment* [#2016] Space Biology**

Cockroaches are potential animals to be sent in space. They are a good source of food (proteins, cockroach milk) while their feaces can be used to produce biologically active soil for vertical farming. Cockroaches synthesise chitin which can be used to manufacture hard and resistant materials.In this work we tested the influence of different types of light on cockroaches breeding and health. Specifically, we tested the influence of sunlight simulator on cockroaches health reflected in measured parameters such as mass, digestion quality and aggressive behaviour. We observed positive effect of tested sunlight

simulator prototype in comparison to standard artificial LED lighting in isolated from sunlight spaces. We used cockroach Gromphadorhina portentosa. 5 adult males, 5 adult females and 10 young middle group nymphs were grouped per sample. Insects were tested regarding various timesof exposure to sunlight simulator: 2, 6 and 12 hours. The first control group was exposed to LED lamps and the second control group was placed in the darkness. Beside huge doses of UV light released by sunlight simulator prototype, even 12 hours of exposure did not disturb cockroaches significantly. Our results suggest that created sunlight simulator is not harmful for living organisms and could be used on board of future spaceships or inside future habitats onMoon and Mars.Experiment was performed during simulations of lunar missions in Analog Astronaut Training Center by analog astronauts.

Garus M.   Nasiek A.   Nowak M.   Ko?odziejczyk A. M.   Harasymczuk M. M.

***Automatic Recognition of Emotions Using Monitoring System During Lunar Analog Simulation* [#2019] Space Biology**

In isolated environments like space stations or extraterrestrial habitats, the mission crew will be put under increased mental strain, what has been proven in multiple studies. Overlooking of increasing stress or anxiety can lead to serious problems like decreasing efficiency or depression. That's why mental health of the crew members need to be constantly overseeing.To achieve this task, we can use support of computer vision and machine learning algorithms, which, along with the continuous monitoring system of the station, can recognize emotions from faces expression. Such system could work as a complementary method to other mental health evaluation tests and be supportive source of data for psychiatric diagnosis.This paper presents proof-of-concept system for automatic recognition of seven basic emotions (happy, neutral, sad, angry, disgusted, frightened, surprised) from face expression recorded via continuous monitoring system during analog Moon mission simulation taking place in space habitat of Analog Astronaut Training Center in Poland, where 5 people crew has been put into one week isolation from the outside world and the solar light.

Hill E. C.   Rivera P. M.   Proppe C. E.   Keller J. L.   Beltran E.

***Applying Heart Rate Variability During EVA-Simulated Activities* [#2026] Space Biology**

Purpose: To describe the application of heart rate variability (HRV) during extravehicular (EVA) activities to provide real-time indicators of an individual's physiological and psychological state. Based on our previous applications of HRV, we hypothesize that it can be efficiently and effectively used to demarcate an astronaut's functional state and will provide an index of activity readiness level that can be used to mitigate risk of injury and mission failure.Background: Astronauts need to display a high degree of mental aptitude, problem solving, critical thinking, and risk-benefit analysis. Astronauts, who frequently experience sleep deprivation, compromised muscle function, increased stress, and changes in diet are at greater risk of developing mission-limited capabilities. We propose the application of HRV as a simple, intuitive measure to indirectly assess an astronaut's functional state prior to performing complicated or rigorous missions such as EVA activities. Additionally, HRV can be used to monitor astronauts in real-time and provide immediate feedback that can be used to quantify the risk of potential injuries or accidents in space.Approach: EVA-simulated activities will be performed in partnership with Kennedy Space Center's Swamp Work Laboratory. Lunar surface will be simulated, and regolith will be brought in to sufficiently recreate Lunar surface and to enhance the efficacy of our research design. Participants will complete a 10-km time trial on a stationary bicycle to induce physiological stress and will then perform a series of mental tests using the Automated Neuropsychological Assessment Metrics to induce psychological stress. Participants will then perform a series of EVA-simulated activities and time to complete task, errors made, perceived difficulty, gate analysis will be quantified. Expected results: HRV will provide a non-invasive assessment of physiological and psychological state. Specifically, performance during the EVA-simulated activities will be correlated with HRV measures to disseminate the ability of HRV to predict or describe potential limitations in individuals experiencing physiological or psychological stress.Conclusion: HRV will provide a quantifiable benchmark used to delineate astronauts that are at risk of comprised EVA activities. These data, which are immediate and intuitive, will be used to reduce potential space hazards while astronauts may be in a state of compromised ability.

Elkatmis B.   Sharma S.   Parisi R.   Agrawal K.   Mohanty A.

***Modeling the Effect of Curcumin on Cancer and Healthy Breast Cells Under Lunar Surface Radiation* [#2031] Space Biology**

The Earth gets exposed to low amounts of cosmic radiation, unlike its counterparts in space, and this phenomenon paved the way for the origins of life. Studies have shown that the radiation levels on the moon are 2.6 times and 200 times higher when compared to the International Space Station and the Earth's environment, respectively[1]. Space radiation becomes a concerning point for human health, owing to future colonization efforts by the government and private entities alike, and the studies on the effects of space radiation and allied fields gain value. Radiotherapy results on breast cancer cell lines like MCF-7 have demonstrated a reduction in cancer cells, and bioactive compounds like curcumin are known to have a cancer-reducing effect on breast cancer[2,3]. In our study, we report a systematic review along with a proposed computational

model to predict and elucidate the effects of the bioactive compound, curcumin on cancer and healthy breast cell lines under radiation conditions on the lunar surface. In our proposed model, we computationally study the WTH3 gene expression, which inhibits cell proliferation by activating tumor suppressor genes and has different expression levels in cancer and normal breast tissue[4]. We aim to examine the level of expression of the WTH3 gene in healthy and MCF-7 cancer cells under the radiation conditions on the lunar surface by using GEO Omnibus and computationally modeling a multicellular system by simulating radiation transport in 3D cell culture systems. The model will employ Geant4 (an open-source radiation transport package), with cancer cell modeling done using NEATG methods[5]. We aim to further employ the cell modeling methods used in a similar study[6], to predict anticancer properties of curcumin when coupled with lunar radiation conditions. The results obtained will be compared with the pre-existing clinical data to provide correlations. In compliance with the results obtained in our models, curcumin based biologics can be applied to astronauts in the lunar environments to solve radiation and cellular-level problems encountered in future colonization missions.

Narayanan S. A.   Caldwell J. T.   Delp M. D.
***Lunar Spaceflight Effects on Lymphatic Function* [#2036] Space Biology**
Astronauts on deep space missions to the Moon will face health risks from simultaneous prolonged exposure to a weightless environment and radiation that is more deleterious than that found on Earth or during LEO missions. Current health concerns include SANS, an operational risk where ocular changes impair astronaut vision. The predominant hypothesis for this adaptation is that spaceflight-induced cephalad fluid shifts leads to elevated intracranial and intraocular pressure and, correspondingly, impaired visual acuity. Whether astronauts traveling outside the Earth's magnetosphere to the Moon are at greater risk to develop SANS is unknown. Results from a study comparing non-flight, LEO astronauts vs. Apollo lunar astronauts suggests Apollo astronauts face elevated cardiovascular risk by space radiation exposure alone, which may influence SANS development and severity. Furthermore, the lymphatics, an understudied area of the cardiovascular system in the context of spaceflight adaptations, support regulation of the cephalic hydrodynamic status. However, there is a paucity of data of how the spaceflight environment effects lymphatic adaptations. This scientific research abstract proposes for study the effects of cephalic lymphatic and glymphatic function and structure from exposure to the spaceflight environment during a mission in Lunar orbit or to the surface. Adaptations of lymphatic and glymphatic function and structure cannot be simulated entirely by Earth-based analogs or low-Earth orbital platforms. Indeed, study of lymphatic and glymphatic adaptations from a Lunar mission would increase our fundamental knowledge of spaceflight cardiovascular system adaptations, as well as provide definitive data on what are considered high-risk health outcomes in astronauts during the course of deep space and Lunar mission.

Spilkin A.   Foing B. PhD   Ko?odziejczyk A. PhD
***Assessing Short-Term Memory and Reaction Time in EMMPOL Analog Astronaut Mission* [#2041] Space Biology**
The study of Human Factors in analog astronaut missions is valuable for better understanding team dynamics and critical skills, such as behavioral skills, memory, decision making and workload management via cognitive tests and physiological signal recordings. During the EMMPOL missions (EuroMoonMars, Analog Astronaut Training Center, Poland), nine analog astronauts took part in cognitive tests that tested their performance in short-term memory and reaction time. Analog astronauts were on a monitored diet, set work schedule and controlled light exposure for the duration of their seven-day mission. The Memory Test (MT) required analog astronauts by recall a list of numbers called aloud and repeating them in reverse order. The MT test was repeated twice a day (afternoon vs. night) and each test consisted of three runs. The Reaction Time Test (RTT) required analog astronauts to interact with a mobile application that is designed to measure one's reaction time (RT) to changing screen color. The RT was also performed twice a day, each test consisting of five runs. Analysis of the MT and RTT results were trial averaged within participants with standard deviation and compared across two conditions. The first condition consisted of studying performance in day versus night trials; the second consisted of comparing the performance as the number of days inside habitat increased. Results demonstrate that seven out of nine analog astronauts increased in reaction time in during night recordings of RTT relative to day recordings by up to 22.3%. The MT results indicated a decreased ability to recall series of numbers in reverse order in five out of nine analog astronauts. The future direction of this investigation will involve Electroencephalography (EEG) recordings that will help determine the brain activity and localization associated to short-term memory recall and stimulus-reaction response.